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4-D TRAJECTORY FRAMEWORK FOR WEATHER INFORMATION

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Motivation

- **Adverse Weather Significantly Impacts Flight Operations**
  - Safety -- 22. 5% All US Accidents
  - Efficiency -- 17% / $1.7B per year Avoidable Weather Delays (Source: FAA)

(Courtesy of NASA)

Thunderstorms & Microbursts

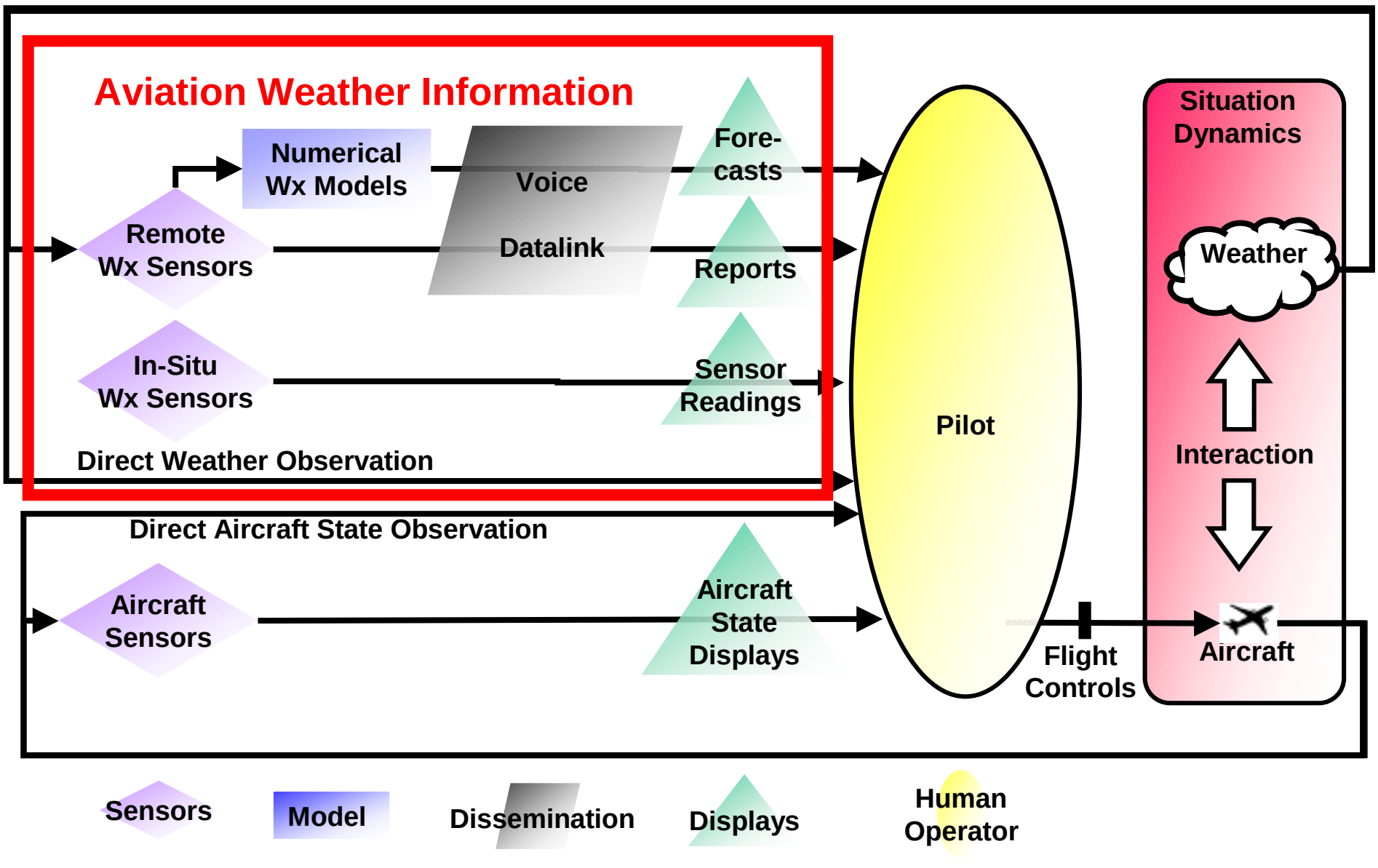
In-Flight Icing

Turbulence & Clear Air Turbulence

- **Effervescence of Weather Information Technical Development**
  - Datalink
- **There is a Need for a Coherent Approach for the Presentation of Hazardous Weather Information to Pilots and Other ATM Decision-Makers**

Human-Centered Approach

Closed Loop Feedback Process



New Weather Datalink Products

ARNAV

Echo Flight

Bendix/King FAA FISDL

Avidyne

Vigyan

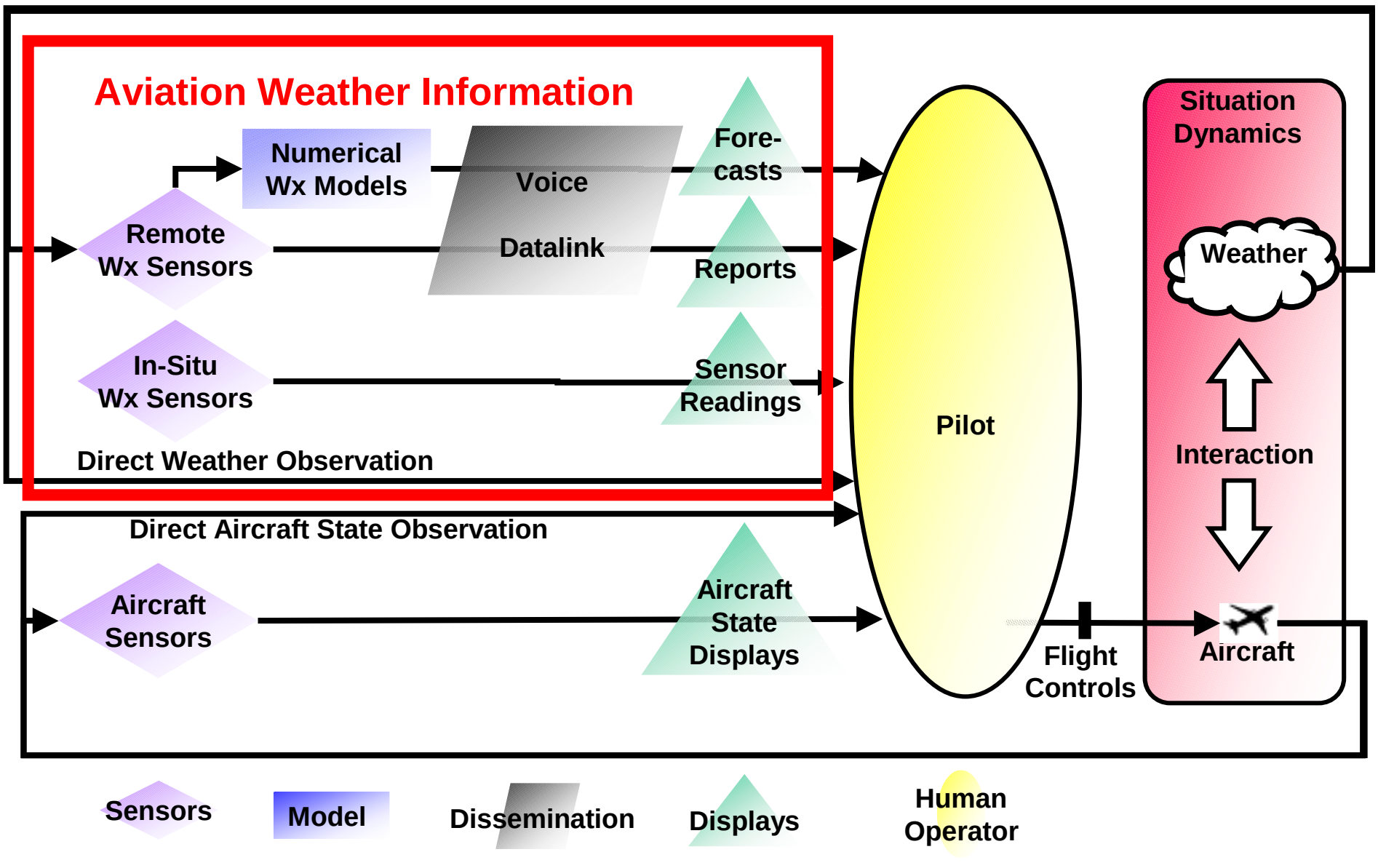
UPS – AirCell

Garmin

Control Vision

Human-Centered Approach

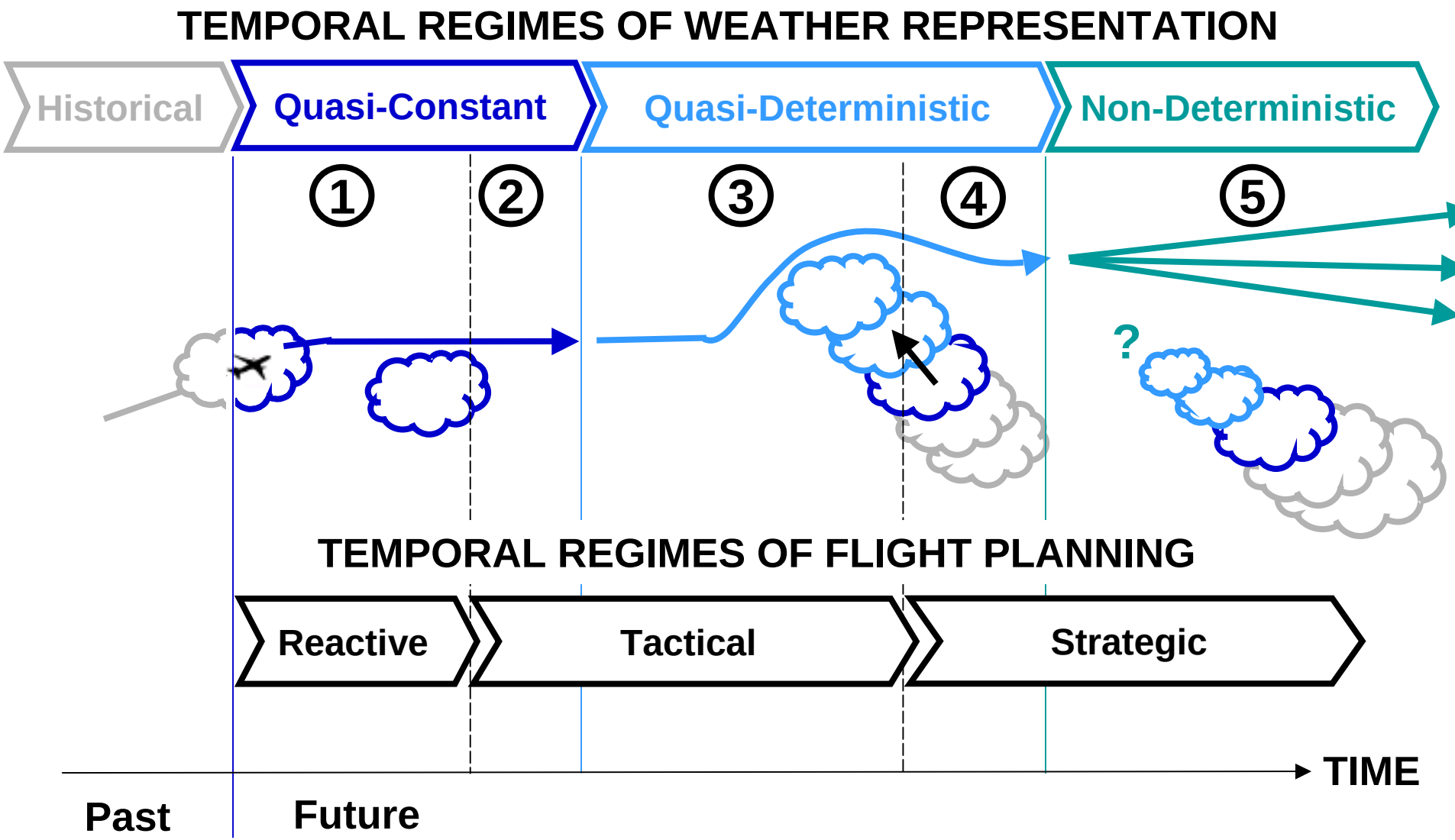
Closed Loop Feedback Process



Pilots' Cognitive Tasks and Information Needs

- **Pilots' Cognitive Tasks**
  - *Identify a planned flight trajectory*
    - *Nominal*
    - *Alternative*
  - *Accept or reject a planned flight trajectory*
    - *Go/no-go*
    - *Continue/deviate*
    - *Fly to destination/alternate*
  - *Select resources for a flight trajectory (e.g., fuel)*
    - *Opt for legal fair-weather minimum or extra fuel*
      - *How much extra fuel?*
  - *Manage systems along a flight trajectory*
    - *When to update weather information*
    - *When to use ice protection systems, seat-belt signs, flight attendant warnings*
- **Pilot weather information needs focus on the spatial distribution of hazardous weather conditions along 4-D aircraft trajectories**
  - *Reactive*
  - *Tactical*
  - *Strategic*

Temporal Regimes of Cognitive Processes



4-D Trajectory Framework

- **Aircraft Trajectory Modeled as a 4-D Aircraft *Hypertube***
  - *3-D space + time*
  - *Specified variables: origin, destination, routing, ETD, ETE, cruising velocity*
- **Weather Field Modeled as Either:**
  - A Spatially Distributed and Temporally Varying Multi-Attribute Field
    - *4D Gridded RUC-2 Data (20 km resolutions, 50 vertical levels)*
  - A Hazardous Weather *Hypervolume*
    - *Assumption: hazardous weather condition thresholds identifiable*
- **Interaction Modeled as the 4-D Intersection of *Hypervolumes***
- **Key Issues**
  - *How to represent time?*
  - *How to represent uncertainty?*

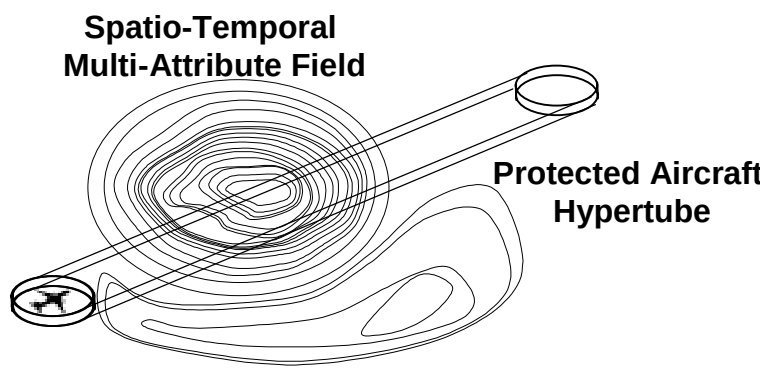
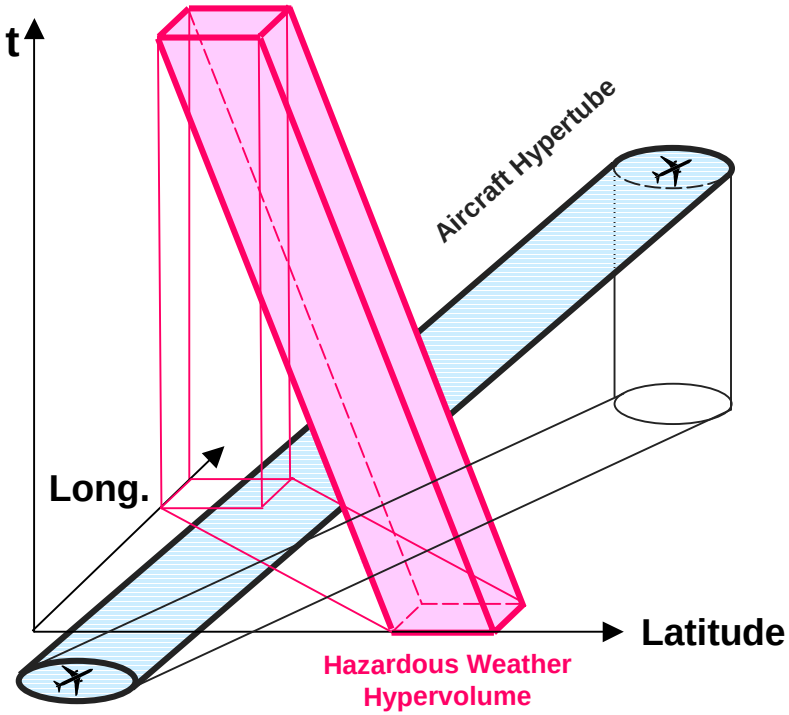
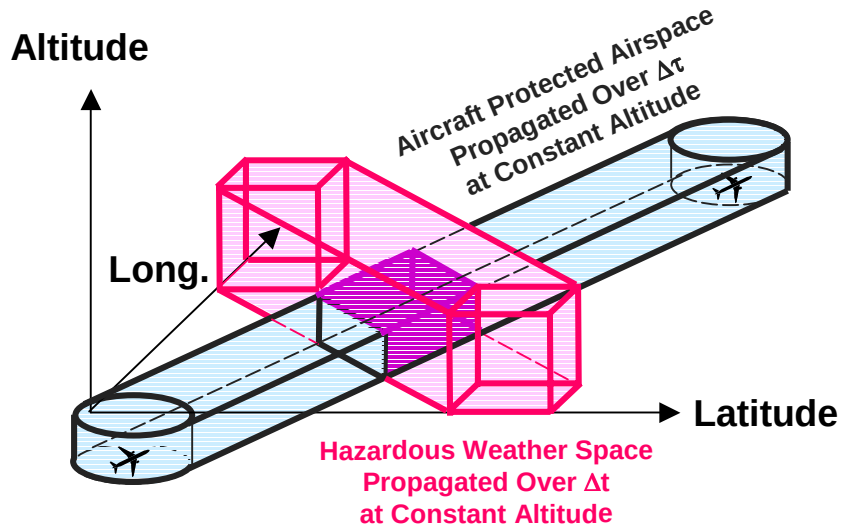
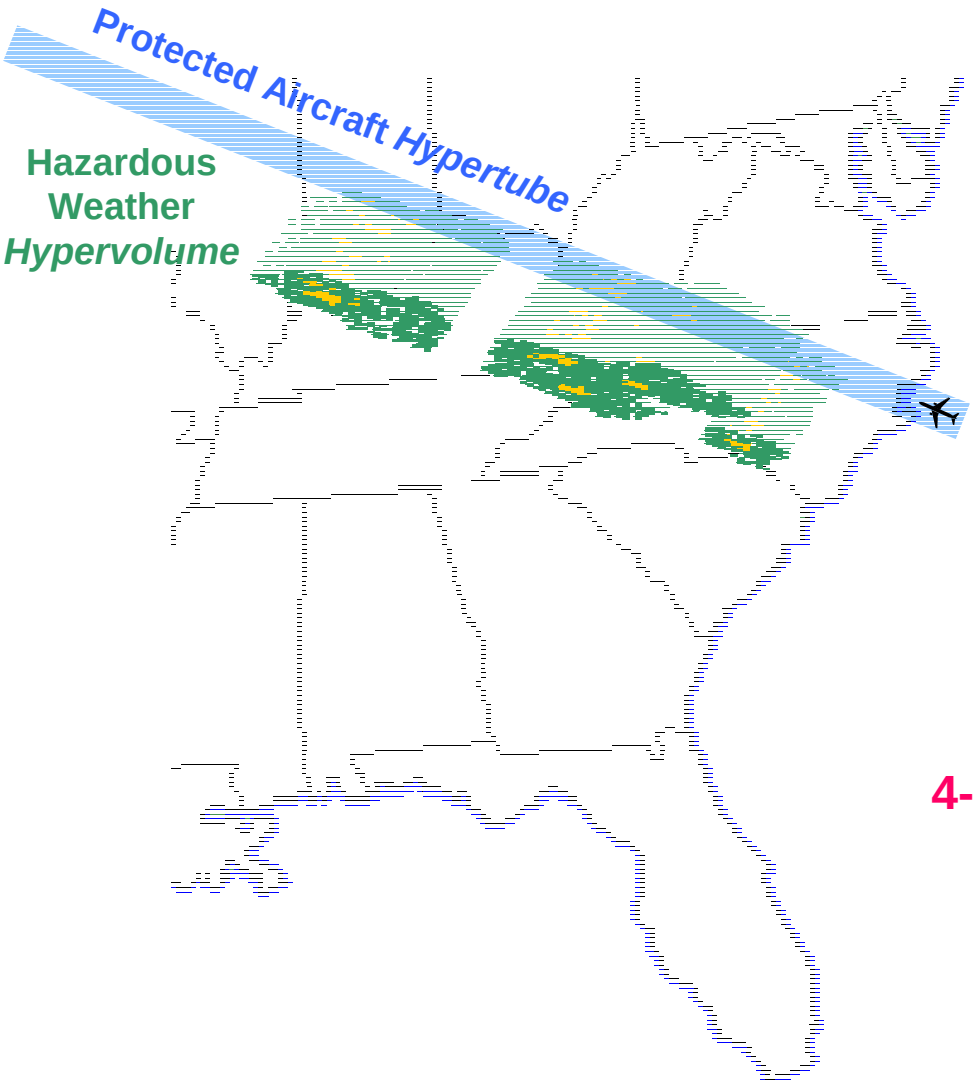


Illustration of 4-D Intersection Test (Quasi-Deterministic Regime)





Pilots' Perception of Forecast Accuracy

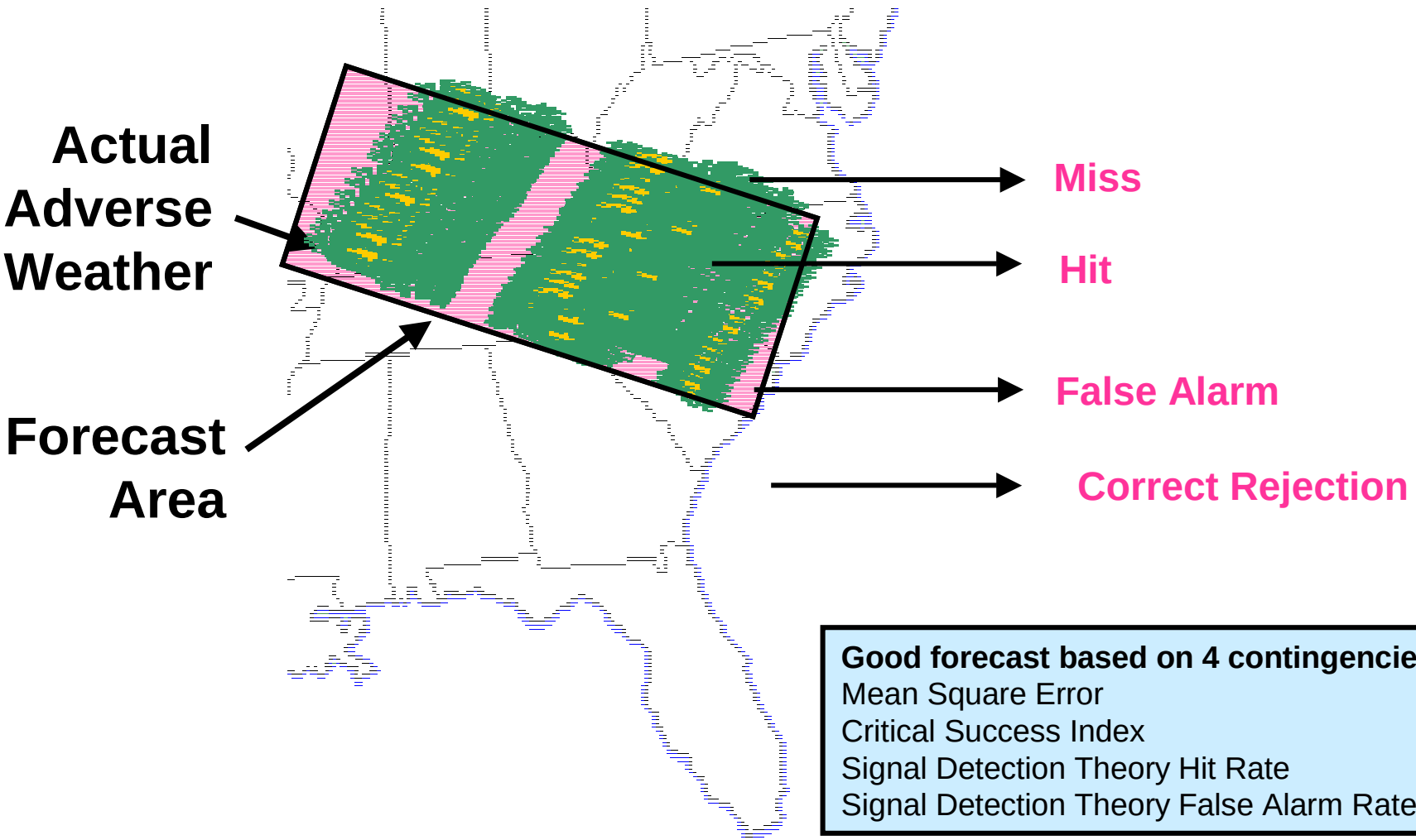


CONTINGENCY MATRIX

Occurrence of 4-D Intersection* \ Prediction of 4-D Intersection*	*Y*	*N*
Y	**Hit**	**Miss**
N	**False Alarm**	**Correct Rejection**

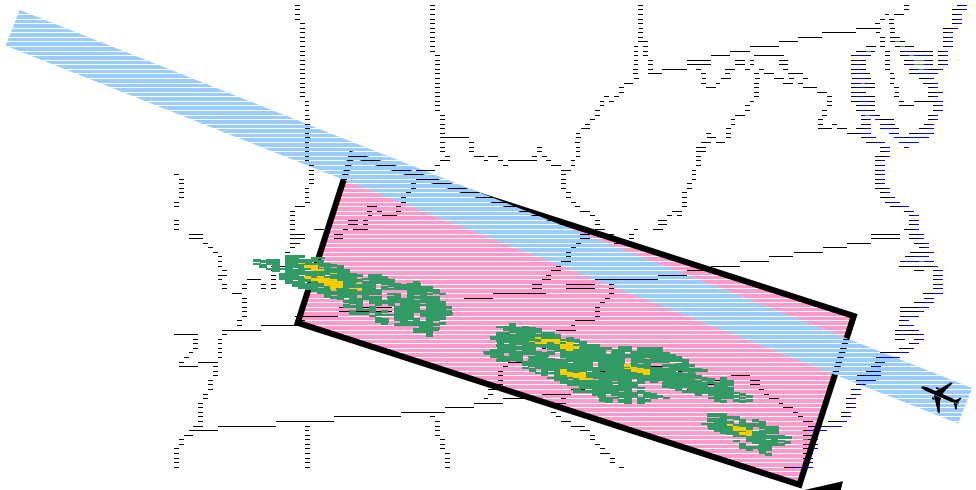
Between Protected Aircraft *Hypertube* and Hazardous Weather *Hypervolume

Traditional Forecast Verification Methodology for ΔT Hours

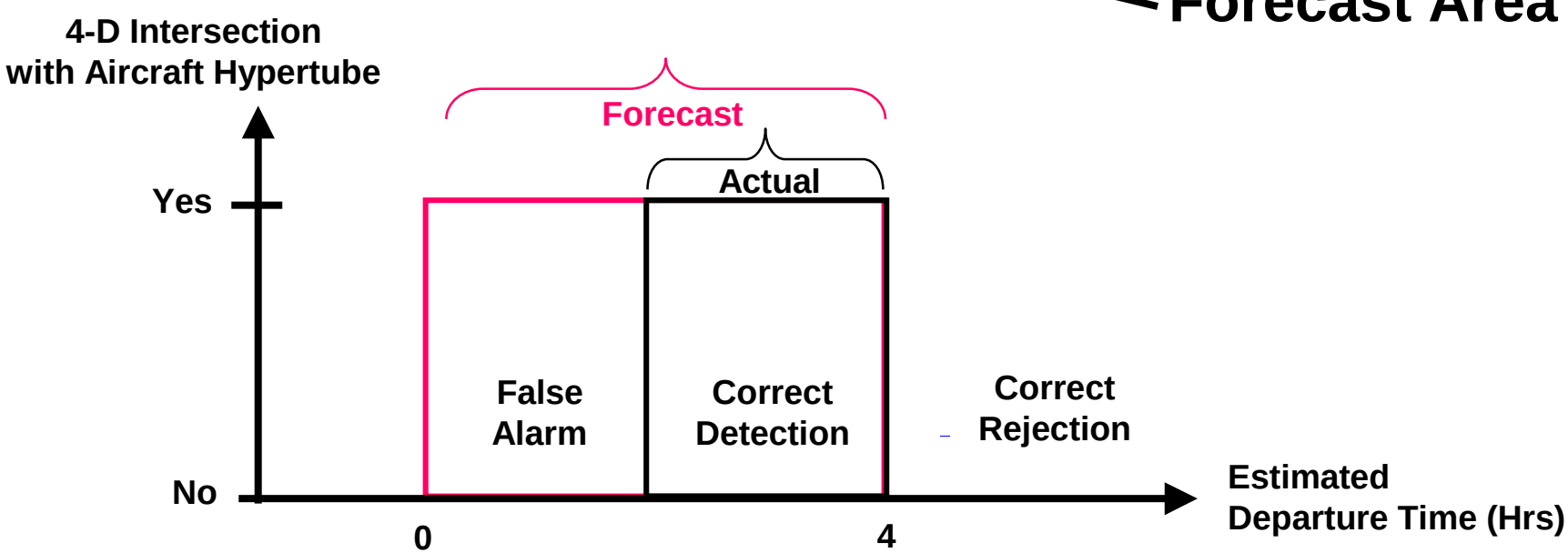


Good forecast based on 4 contingencies above:	
Mean Square Error	14%
Critical Success Index	73%
Signal Detection Theory Hit Rate	89%
Signal Detection Theory False Alarm Rate	17%

Sensitivity of 4-D Intersection to Estimated Time of Departure



Forecast Area



Conclusions

- **Limitations currently exist in the dissemination and representation of temporally varying weather information**
  - Weather datalink capabilities are improving the dissemination potential to pilots
- **These limitations impair the ability to provide weather forecasts that can be perceived accurate by users of aviation weather information**
- **The 4-D trajectory framework serves as a basis for investigating across the flight deck, ATC and AOC environments:**
  - How to represent temporally varying information
  - How to represent uncertainty in the adverse weather avoidance problem
- **Continuing Work**
  - Advanced Visualization Techniques for 4-D Fields
  - Trade-Offs in Representing Uncertainty in Quasi-Deterministic Regime
  - Representation of Weather in Non-Deterministic Regime